IZEMBEK NATIONAL WILDLIFE REFUGE OIL AND GAS ASSESSMENT

by
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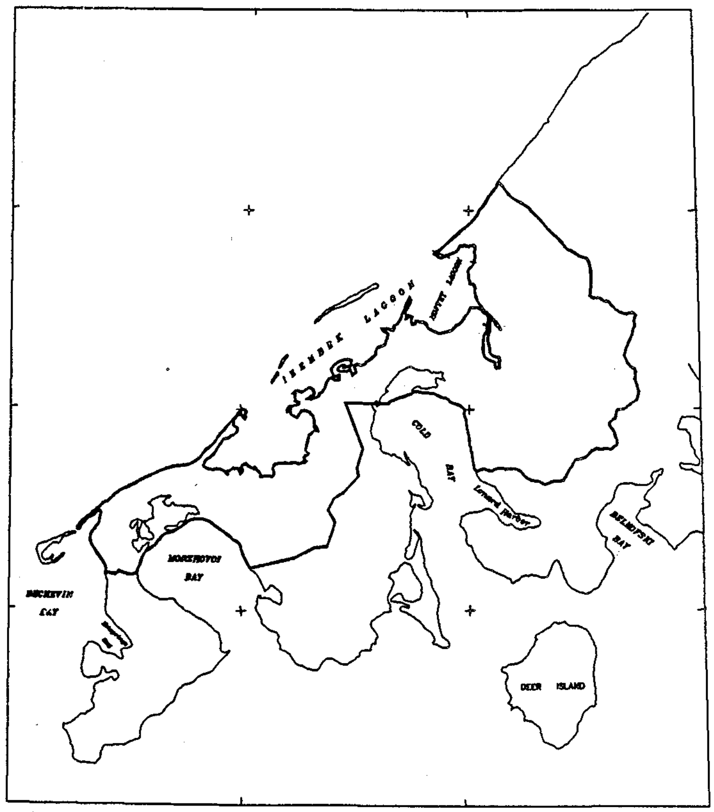
December 1988



U.S. Department of the Interior
Bureau of Land Management - Alaska
Division of Mineral Resources
Branch of Mineral Assessment

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EXECUTIVE SUMMARY

The Izembek National Wildlife Refuge, near the southern tip of the Alaska Peninsula, has a small area in its northeastern corner which we classified as having HIGH geologic potential for the geologic occurrence of hydrocarbons. The rest of the refuge we classified as having NO to LOW geologic potential for the occurrence of hydrocarbons. We lack subsurface data from within the refuge and base these classifications on extrapolations of data from outside the refuge.

We classified the entire refuge as having NO to LOW economic potential. The area classifed as having HIGH geologic potential is small and could not likely stand on its own merits to support production. Also, the nearest subsurface data comes from a well located 19 miles away and the HIGH geologic potential can be considered as very speculative.

INTRODUCTION

The Bureau of Land Management (BLM) has entered into a Memorandum of Understanding with the U.S. Fish and Wildlife Service (FWS) to assess the oil and gas resources of the National Wildlife Refuge System in Alaska. Section 1008 of the Alaska National Interest Lands Conservation Act (ANILCA) requires the Secretary of the Interior to initiate an oil and gas leasing program on the Federal lands of Alaska. ANILCA exempts " . . . those units of the National Wildlife Refuge System where the Secretary determines, after having considered the national interest in producing oil and gas from such lands, that the exploration for and development of oil and gas would be incompatible with the purpose for which such unit was established."

The BLM's role is to help fulfill that part of Section 1008 that mandates:

> "In such areas as the Secretary deems favorable for the discovery of oil or gas, he shall conduct a study, or studies, or collect and analyze information obtained by permittees authorized to conduct studies under this Section, of the oil and gas potential of such lands and those environmental characteristics and wildlife resources which would be affected by the exploration for and development of such oil and gas."

This report is intended to assist the FWS in deciding which lands within the Izembek National Wildlife Refuge (NWR) should and should not be opened to oil and gas leasing/development. This report identifies those areas in and around the refuges which are favorable for the discovery and development of oil and gas.

HISTORY OF GEOLOGIC EXPLORATION

G. W. Steller, a biologist who visited the Alaska Peninsula with Vitus Bering in 1741, made the first geological observations of the Peninsula. Constantine Grewingk, in 1850, published a geologic report based on data compiled from prospectors, traders, trappers, and reports from scientific expeditions. After the purchase of Alaska from Russia in 1867, W. H. Dall laid the groundwork for direct study of the Alaska Peninsula (Burk, 1965).

The U.S. Geological Survey, over the years, has sent numerous investigators to the Alaska Peninsula. The Peninsula also has attracted prospectors for oil and gas as well as for hard rock minerals, over the years. Based on the presence of oil and gas seeps in the vicinity of Puale Bay, then known as Cold Bay, several oil exploration wells were drilled in the early 1900s.

In 1910, oil lands in Alaska were withdrawn from entry (Martin, 1921). The Mineral Leasing Act of 1920 renewed interest in the search for oil on the Alaska Peninsula.

A total of 26 wells have been drilled on the Alaska Peninsula. The closest ones to the Izembek NWR include the Amoco Cathedral River No. 1 and the Pan American Petroleum Corporation's David River Nos. 1 and 1A, about 19 and 41 miles to the northeast, respectively.

LOCATION AND PHYSIOGRAPHY

The Izembek NWR covers 320,893 acres along the Bering Sea coast at the southwestern tip of the Alaska Peninsula. The refuge surrounds Izembek Lagoon. It has glacier-capped volcanoes, valleys, and tundra uplands that slope into the lagoons along the Bering Sea.

STRATIGRAPHY AND LITHOLOGY

The Alaska Peninsula is primarily a province of Mesozoic and Cenozoic sediments heavily influenced by volcanic and plutonic activity. Figure 1 illustrates the section in the Cathedral River and David River wells to the northeast of the refuge. The following sections describe the formations in these wells as found in various parts of the Alaska Peninsula, outside the Izembek NWR. No subsurface geologic data and little surface geologic data is available for the area within the Izembek Refuge. Refer to plate 2 in Bascle et al. (1987) report on the Alaska Peninsula/Becharof National Wildlife Refuges Oil and Gas Assessment for locations.

TRIASSIC

Martin (1905) first identified Triassic rocks on the Alaska Peninsula in the Puale Bay area and on Cape Kekurnoi. These rocks include limestone, chert, shale, and volcanic and igneous rocks (Brooks, 1918; Martin, 1921; Capps, 1923). Jones et al. (1981) described the Upper Triassic rocks as a well-stratified sequence of limestone, chert, tuff, and agglomerate up to 2,250 feet (740 m) thick (Keller and Reiser, 1959).

Kellum et al. (1945), described the limestones, along the northeastern shore of Puale Bay, as dark, blue-gray, dense, thin-bedded limestones that weather light-gray to buff. Near Cape Kekurnoi, the limestones become more massively bedded with beds ranging up to 85 feet (28 km) thick. Fine-grained, calcareous sandstones often accompany the very thin-bedded shale. Calcareous shale, common in the upper parts of the section, is less common than limestone. Much of the material is thought to be tuffaceous, and where the amount of volcanic material is high, the rocks are greenish. Tuffaceous sandstone interbedded with the limestone and shale in the upper part of the section, and, near the top, is nearly as abundant as limestone.

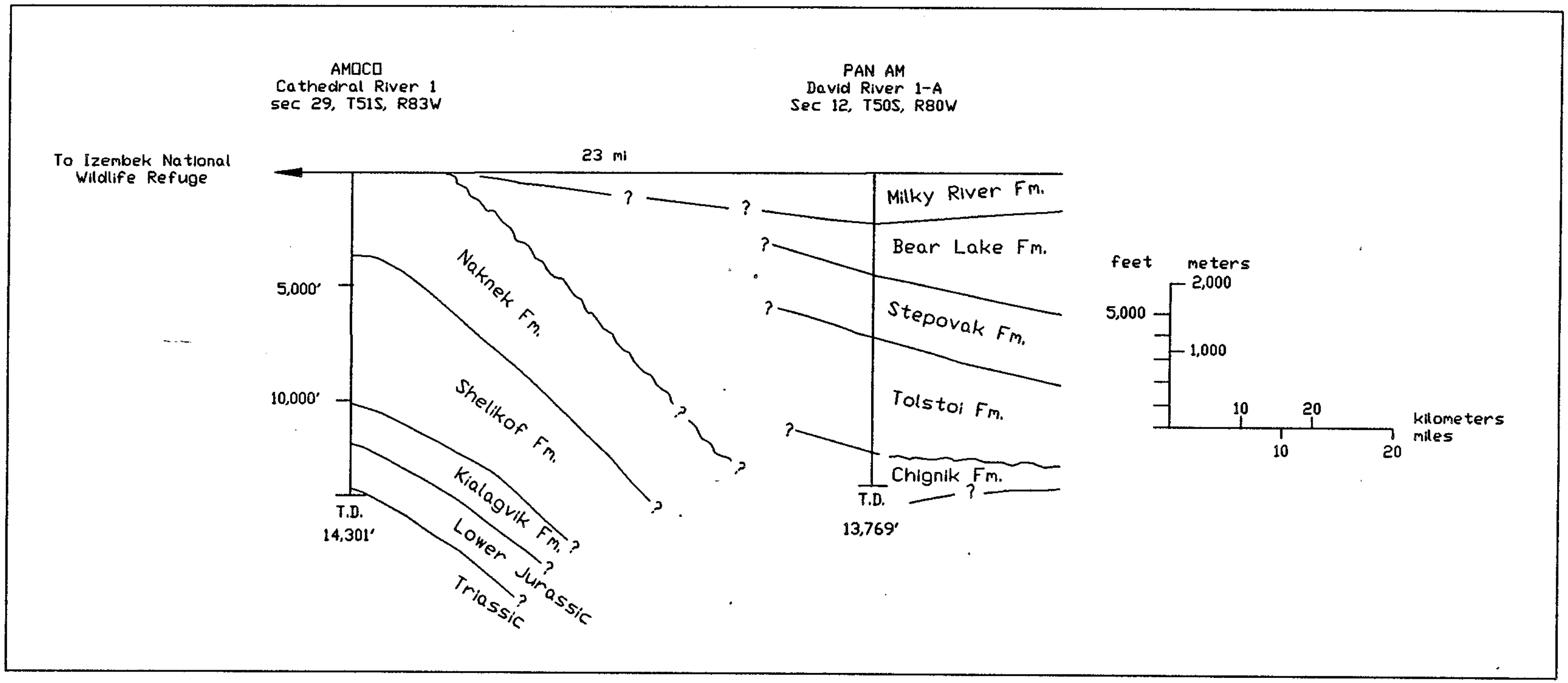

Figure 1. Stratigraphic cross-section through the wells to the northeast of the Izembek National Wildlife Refuge. (modified from Brockaway et al., 1975 and McLean, 1977)

Capps (1923) described the volcanic and igneous rocks as basaltic dikes and sills. Stone and Packer (1979) described them as chiefly detrital volcanic rock and extrusive flows, and Jones et al. (1981), described them as tuff and agglomerate.

JURASSIC

Unnamed Lower Jurassic

Lower Jurassic rocks are exposed on the Alaska Peninsula near Puale Bay and Alinchak Bay (Capps, 1923). Rocks exposed on Cape Kekurnoi represent the oldest Jurassic rocks in the area. The section exposed at Puale Bay consists of two lithologic units. The lower unit has 780 to 1,000 feet (256 to 328 m) of mainly calcareous sediments, and the upper unit has 1,040 to 1,300 feet (341 to 427 m) of mainly clastic sediment (Kellum et al., 1945). The lower unit has massive to thin-bedded calcareous sandstone with interbedded calcareous shale and limestone. Agglomerate and conglomerate form a considerable portion of the unit. Coarser clastic material accounts for about 70 percent of the lower unit.

The upper unit, mainly a dark, gray-black shale has a few thin beds of light colored, coarse-grained, well-indurated sandstone (Kellum et al., 1945). The amount of sandy shale and sandstone increase near the top of the unit. This upper, more sandy part contains limey concretions and partings. A conglomerate, with boulders up to two feet in diameter, and sand lenses that form a crude bedding, overlies the sandy part.

The Lower Jurassic rests unconformably on latest Triassic age limestone. The lower unit contains ammonites of Hettangian age (Imlay, 1981); the upper unit contains ammonites of Sinemurian age. Sandy siltstone of the Kialagvik Formation overlies the unnamed Lower Jurassic, possibly by fault contact.

Kialagvik Formation, Middle Jurassic

The Kialagvik Formation represents the Middle Jurassic rocks on the Alaska Peninsula. At Kialagvik Bay, it consists of 500+ feet (164+ m) of sandstone and shale. It crops out in the southwestern half of the Wide Bay area. The wells drilled in the area may have penetrated the Kialagvik Formation. Some of the strata that crop out on the north shore of Puale Bay have been referred to the Kialagvik by some geologists (Capps, 1923; Smith and Baker, 1924). About 1,750 feet (574 m) of Kialagvik crops out along Short Creek. Oil seepages have been reported from the Kialagvik on Wide Bay. Onshore geology and offshore seismic data indicate that the Middle Jurassic (?) rocks occur in the subsurface throughout the area between the Bruin Bay Fault to somewhere offshore in the Shelikof Strait. No Kialagvik occurs in the Aniakchak area.

Shelikof Formation, Middle Jurassic

The Middle Jurassic Shelikof Formation is the main formation on the northwest shore of Shelikof Strait (Capps, 1923; Smith and Baker, 1924; Kellum et al., 1945; Wilson, 1980) from Katmai Bay at least as far southwest as Wide Bay. It is not present in the Aniakchak area. It ranges from 5,000 to 7,000 feet (1,640 to 2,300 m) thick and has three lithologic units.

The lower member, in the Wide Bay area, is generally soft and brown-weathering in the lower part, but gets harder and darker gray upward on both fresh and weathered surfaces (Imlay, 1953; Wilson, 1980). The lower member, about 800 feet (260 m) thick, contains many sandy interbeds that range from a few inches to as much as 200 feet (66 m) thick. Thin beds of white to yellowish-brown, fine-grained material, probably volcanic ash, fairly common in the lower part of the member, serve to distinguish the basal siltstones from the underlying Kialagvik Formation. Limestone concretions are abundant at many levels. Ashy beds similar to those in the lowest Shelikof Formation in the Wide Bay area give the outcrops a brown appearance. About 100 feet (33 m) of coarse conglomerate underlies the siltstone and rests on the Lower Jurassic siltstone. The ammonite fossil Cadoceras occurs throughout the lower member (Detterman, Yount, and Case, 1981). The middle and upper parts of the member contain many specimens of Pseudocadoceras and Lilloettia.

The middle member consists mostly of massive gray sandstone, but contains interbeds of siltstone and lenses of conglomerate, with granitic and dioritic rocks (Imlay, 1953; Wilson, 1980). It is generally fine, but in places contains boulders up to two feet in diameter. Locally, the sandstone in the upper part appears to pass laterally into siltstones of the upper member. This unit has yielded pelecypod, gastropod, belemnite, ammonite, and brachiopod fossils.

The upper member consists mostly of hard, dark-gray, gray-weathering siltstone (Imlay 1953; Wilson, 1980). Near Wide Bay, the siltstone contains thin interbeds of sandstone and limestone. Near Puale Bay, the siltstone contains lenses of yellowish-weathering limestone. The fossils in this unit include pelecypods, gastropods, and belemnites.

Naknek Formation, Upper Jurassic

The Naknek Formation, named the Naknek Series by Spurr (1900), consists of well- to poorly-bedded arkosic sandstone, conglomerate, siltstone, and mudstone (Capps, 1923; Smith and Baker, 1924; Lyle et al., 1979). These either interbed or form relatively thick exposures of a single lithology. The matrices of the sandstones and conglomerates typically consist of feldspar, quartz, volcanic rock fragments, and chert. Granitic and metamorphic rocks predominate among coarser clasts in the siltstones and mudstones. Quartz typically exceeds feldspar in the fine-grained rock types, whereas feldspar commonly exceeds quartz in the sandstones and conglomerates.

The Naknek Formation, exposed along most of the length of the Peninsula, reaches a thickness of about 10,000 feet (3,000 m) in the Wide Bay area. The Chignik area has over 1,000 feet (328 m) of sandstone, conglomerate, arkose, and shale (Martin, 1926). At Chignik Lagoon, it has yielded fossils of *Aucella concentrica* and certain undescribed species of the ammonite *Phylloceras*, the pelecypod *Lima*, and the gastropod *Delphinula* (Keller and Cass, 1956). *Aucella concentrica* provides evidence of late early to middle Late Jurassic age and indicates a position low in the Naknek.

In the Mount Katmai area, it crops out in a continuous mountain belt 20 to 38 miles (32 to 61 km) wide (Keller and Reiser, 1959). This belt trends northeastward across the entire area. On the northwest side of its outcrop belt, it is in fault contact with igneous rocks of Early and/or Middle Jurassic age. Rocks of Cretaceous age overlie it in the northeast part of this area. Both here and over much of the central part of the area, volcanic rocks of Tertiary and Quaternary age overlie it. A high organic content is reported in the Katmai National Monument area and in rocks of this age at Hallo Bay.

In the Chignik-Sutwik Island area (Detterman, Miller, *et al.*, 1981), the two unnamed members have a combined thickness of 4,570 to 5,485 feet (1,500 to 1,800 m). The lower member is mainly arkosic sandstone and conglomerate. It is light- to medium-gray, fine- to coarse-grained, and generally thick-bedded to massive. It is commonly cross-bedded and laminated, with magnetite grains forming the dark laminae. Granitic clasts form the major part of the conglomerate. Clasts of chert and white quartz, in about equal amounts, form the remainder. The unit collected in a fluvial nonmarine environment. Its fossil assemblage includes carbonized plant debris, sparse *Aucella* pelecypods, and sparse ammonites. It disconformably overlies the Shelikof Formation and gradationally and conformably underlies the Staniukovich Formation.

The upper member, a thick sequence of arkosic conglomerate and arkoses, grades upward to feldspathic siltstone, and with increasing grain size, to a boulder conglomerate toward the west near Lower Ugashik Lake. The unit, at least 5,000 feet (1,640 m) thick, may be as great as 10,000 feet (3,280 m). No exposures are known west of this unit's intersection with the Bruin Bay Fault.

Blasko (1976) reported oil seepages from the Naknek in the Puale Bay area. There the Naknek consists of a series of dark shales with some limestone beds. It also has 5,000 feet (1,640 m) of conglomerate and arkosic sandstone overlain by sandy shale at Puale Bay.

In the Aniakchak region, the Naknek consists of mudstone, shale, and fine sandstone with minor amounts of limestone (Knappen, 1929). The sandstone grades into a shale or light-gray to chalky-white arkose with quartz, feldspar, and granite fragments 1 to 4 mm in diameter. The arkose increases abundance to the northwest. The sandstone and arkose, in a few places, contains lenses of conglomerate.

Black or dark-gray mudstone and shale constitutes fully 65 percent of the Naknek and grades into fine sandstone. Together, these make up more than 95 percent of the formation. Few of the sand grains exceed 0.2 mm in diameter. The sandstone is almost indistinguishable from the enclosing black and dark-gray mudstone and shale. The arkose is olive drab, yellowish, or light gray and coarse grained. Beds cannot be traced over long distances. Boulder size decreases steadily north to south and northeast to southwest, as does the percentage of conglomerate, the amount of arkose, and the evidence of contemporaneous erosion. Cross-bedding and ripple marks indicate transport to the south and southwest. No plant fossils have been reported in the Aniakchak area, only numerous marine fossils. The formation reaches a thickness of about 6,400 feet (2,100 m) in the Aniakchak area.

The Naknek is the oldest formation exposed on the northern shore of the Alaska Peninsula (Marlow et al., 1979). The siltstone of the Naknek grades upward into arkosic sandstone of the Staniukovich Formation in the Port Moller area.

The Naknek, as exposed in bluffs and low beach cliffs in the Black Hills area (McLean 1979), consists of gently-dipping, fine-grained or arkosic sandstone. Strata are massive- to thin-bedded and nearly devoid of structure. Clayey matrix, calcite, and laumontite make up the cementing material. The average composition of four fine- to medium-grained sandstones is reported as 18 percent quartz, 80 percent feldspar, and 2 percent lithic fragments. The sandstone composition indicates a volcanic and granitic source terrane. The molluscan assemblage of pelecypods, belemnites, and rare ammonites and gastropods indicates a shallow marine environment of deposition.

TERTIARY

Belkofski Formation, Lower Tertiary

Kennedy and Waldron (1955) applied the name, "Belkofski Tuff" to a sequence of volcanic sandstones, conglomerates, and breccias exposed along the shore between Pavlof Bay and Cold Bay. They estimated the thickness of this unit at more than 3,000 feet. Burk (1965) mapped these rocks and the underlying "green arkose" as the Belkofski Formation.

The Belkofski consists mostly of nonmarine, volcanic sandstone with thin beds of black carbonaceous mudstone. More specifically, it consists of fine- to coarse-grained sandstone, pebble to cobble conglomerate, and breccia. All of these are made up of volcanic debris of various types. Typically, this sequence of rocks shows rapid facies changes. The rocks generally are somber shades of gray, greenish-gray, or gray-brown. The Belkofski also contains a welded ash-flow tuff, andesitic dikes and sills, and several quartz diorite stocks.

The Belkofski contains molluscan fauna and numerous, poorly preserved plant fossils. _Andara_ sp., _Macoma_ sp., and _Mya_ sp. are pelecypod generally found in the Belkofski Formation. These probably indicate an Oligocene age.

Pliocene-Pleistocene fluvial gravels capped by probable Pleistocene andesitic and basaltic flows probably overlie the Belkofski.

IGNEOUS ROCKS

The Alaska Peninsula has had a long history of igneous activity and, as would be expected, igneous rocks account for a substantial proportion of the rocks of the Peninsula. These igneous rocks run the range from massive intrusive batholiths through intrusive dikes and sills to volcanic extrusives and ejecta. Frosty Peak rises along the southern boundary of the refuge.

STRUCTURE

Widely spaced, northeast-striking, monoclines, anticlines, and synclines characterize the area from Mt. Veniaminof to Cold Bay. The faults in this area are all large. The reverse fault near Beaver Bay displaces Paleocene and Eocene rocks from the Oligocene rocks. Dips up to 80° occur in the vicinity of this fault (Hanson _et al_., 1981). There is little information on the structure within the refuge's boundaries.

TECTONIC SETTING

The Alaska Peninsula lies at the northern edge of the Pacific Ocean and, also, at the northern edge of the lithospheric plate which underlies the Pacific Ocean. The Pacific plate moves northward with respect to the Alaska Peninsula and Aleutian Islands and is subducted beneath them in the Aleutian Trench. As the Pacific plate underthrusts the Peninsula/Arc system, it creates great tectonic stresses and is also consumed into the mantle. Relief of these stresses occurs through earthquake and volcanoic activity which has been important in the geologic development of the Alaska Peninsula and Aleutian Island Arc.

Paleomagnetic evidence indicates that the rocks of the Peninsula formed at a more southerly latitude than that at which currently located. Lithospheric plates carried these rocks northward and plastered them on to what is now Alaska as the Alaska Peninsula.

Volcanic rocks, indicative of former volcanic island arcs, are common on the Alaska Peninsula back to the Late Paleozoic. The Alaska Peninsula, apparently, has had a long and complex tectonic history related to the movement of lithospheric plates over the surface of the earth.

Two distinct, but related tectonic provinces make up the Alaska Peninsula. These have been identified and defined as the "Illiamna" and "Chignik" sub-terranes of the Alaska Peninsula Terrane. North of Becharof Lake, the Bruin Bay fault separates these two terranes. How far south the Illiamna terrane may extend in the subsurface is unknown. These two sub-terranes have shared a "limited common geologic history." They share some rock units in common and one has served as a source terrane for the other from time to time (Wilson et al., 1985).

The Illiamna sub-terrane consists of "Paleozoic and early Mesozoic rocks intruded by the Alaska-Aleutian Range batholith of Jurassic to mid-Tertiary age and including the batholith itself." The sub-terrane lies north of the Bruin Bay fault and "is composed of moderately deformed early Mesozoic marine sedimentary and volcanic rocks and schist, gneiss, and marble of Paleozoic and Mesozoic age . . . in close proximity to and intruded by . . . batholith," (Wilson et al., 1985).

The Chignik sub-terrane consists of "little deformed shallow marine to continental clastic sedimentary rocks." Important constituents of the older rocks of the sub-terrane include deep marine, volcaniclastic, and calcareous rocks (Wilson et al., 1985). The Chignik sub-terrane lies to the south and east of the Bruin Bay fault and extends to the tip of the Peninsula.

GEOLOGIC HISTORY

The two small exposures of middle Paleozoic limestone that crop out near Gertrude Creek represent deposition in warm shallow seas. The significance of these two outcrops in the geologic history of the Alaska Peninsula is, however, difficult to assess. This difficulty arises from the extremely limited size of the outcrops and the lack of correlatable units in the vicinity. Detterman et al. (1979), have interpreted them as possible roof pendants in the Alaska-Aleutian Range batholith.

The outcrops of fossiliferous limestones at Cape Kekurnoi, again, tells us of deposition in warm shallow seas during Permian time. The volcanic rocks associated with the limestones indicates a possible island arc setting similar to the Aleutian Island arc, but in a warmer climate. This warmer climate could be due to a more southerly position for these rocks or to a more widespread "tropical" climate. This situation continued through the Triassic and into the lower Jurassic as more limestones and volcanic rocks collected. Although violent volcanic activity left its record in the rocks of Permian through Lower Jurassic age, the general environment recorded is one of long-lasting persistence with little change.

The middle Jurassic Kialagvik Formation overlies the unnamed Lower Jurassic rocks, whether by fault contact or unconformity is unclear. These rocks indicate a change in depositional environment, and they consist of sandstone and shale. Ammonites in the Kialagvik Formation indicate deposition in a marine environment, but one that is no longer conducive to the deposition of limestone. Volcanoes left no record in the rocks of the Kialagvik Formation.

Volcanic activity apparently resumed in the Upper Jurassic as the marine Shelikof Formation contains beds of probable volcanic ash. A new feature shows up in the Shelikof, conglomerates containing boulders of granitic and dioritic rocks. These rocks probably derived from the Naknek Lake batholith now uplifted to the north of the Bruin Bay fault. The uplift of the Naknek Lake batholith becomes more evident in the overlying Naknek Formation, which consists of arkosic sandstone, conglomerate, siltstone, and mudstone. Fossil content indicates that the Naknek Formation formed in a marine environment.

The Tertiary brought a renewal of volcanic activity to the Alaska Peninsula area. Peaks of volcanic activity apparently shifted through time and greatly influenced the local nature of the deposits. The deposits range from non-marine alluvial to fully marine with volcanic character varying from virtually nil to totally volcanic in nature. Not only did the volcanic activity shift through time, but the centers of deposition also shifted in response to volcanic and tectonic activity.

A period of uplift and erosion, that lasted into the Miocene, followed deposition of the Paleogene sediments. The Miocene rocks record erosion of the batholiths, which intruded during the Early Tertiary, and older sedimentary and volcanic rocks. Coarse rocks record rapid uplift in the source areas and deposition in nearby, mainly non-marine, environments. These rocks also contain volcanic rocks indicating volcanically active source areas. The fine-grained sediments overlying, and interfingering with, these rocks record deposition in shallow-marine environments as marine waters once again deepened over parts of the Alaska Peninsula. Uplift and erosion, in the late Miocene or early Pliocene, once again affected the Alaska Peninsula.

In some locales, subsidence again allowed marine conditions to transgress over parts of the Peninsula during the Pliocene. Volcanism continued to play a role in shaping the Peninsula. Uplift and erosion once again followed subsidence and deposition.

Pleistocene and Recent rocks and sediments record the advance and retreat of glaciers and continued volcanic activity. The most recent rocks and sediments continue to record the types of conditions that have shaped the Peninsula through much of its history. Volcanic activity, older sedimentary and volcanic rocks, and plutons provide abundant material for deposition in non-marine and marine environments. Details have changed, but the general picture remains much the same.

The history of the Alaska Peninsula has been explained in terms of plate tectonics. One of the current theories calls for the Peninsula to have formed as microplates which have migrated from a more southerly position. This theory explains the changes from warm climate conditions, as evidenced by the Permian and Triassic limestones and the Jurassic Herendeen Limestones, to cold climate conditions extant on the Peninsula. It also explains the paleomagnetic data which indicates not only a more southerly position, but also a rotation of the Peninsula into its current position. Plate tectonics also explains the igneous plutons and the abundance of volcanic material present in the rocks of the Peninsula. These formed as a result of subduction of one plate under another. Each of three major batholiths may record the presence of an island arc.

RESERVOIR ROCKS

Any rocks with interconnected pore space can serve as a reservoir rock for hydrocarbons. Sandstones, limestones, and dolomites, however, generally make the best reservoir rocks. In special circumstances, other types of rocks also form oil reservoirs. Oil has been found in shales, slates, and igneous rocks (Levorsen, 1967). For this report, sandstones and limestones serve as the possible reservoir rocks on the Alaska Peninsula. No dolomites have been found on the Peninsula, and the probability of shale, slate, or igneous rocks acting as reservoirs is low.

The lack of detailed data on the Paleozoic, Triassic, and Jurassic limestones found on the Peninsula makes it difficult to assess the likelihood that these rocks serve as reservoirs. About the most that can be said is, given the right combination of a structural or stratigraphic trap and porosity, limestones could serve as oil reservoirs. The most likely location to look for possible limestone reservoirs would be in the vicinity of Puale Bay and Wide Bay. The distribution of these limestones in the subsurface is unknown.

Sandstone accounts for a large portion of the stratigraphic section of the Alaska Peninsula. The major drawbacks to these sandstones serving as oil reservoirs is their large percentage of volcanic rock fragments, plutonic rock fragments, sedimentary rock fragments, and feldspars. Rock fragments and feldspars tends to degrade a sandstone as a potential reservoir. Through diagenesis, they can convert to clays which can clog pore spaces. Through applied pressure, they can deform around more rigid grains and squeeze pores out of existence. Intergranular cement, such as calcite and laumontite, also reduce porosity in the sandstones of the Alaska Peninsula.

Some of the sandstones of the Alaska Peninsula have been found to have good porosities despite these drawbacks. Most reported porosities are, however, quite low. Lyle et al. (1979), report that "selected outcrop samples and well log analyses indicate that the porosity of some of the potential reservoir rocks has been preserved." They report porosities of up to 20.1 percent in the formations of the Alaska Peninsula. Keller and Cass (1956) report an effective porosity of 13.1 percent in a petroliferous sandstone. Marlow et al. (1979), report porosities as high as 36.5 percent in the Gulf Sandy River No. 1 well. Porosities as low as 8 percent in sandstones can form producible reservoirs and porosities of 15 percent can form reservoirs of good quality.

The early migration of hydrocarbons into a sandstone can preserve the primary porosity of a sandstone. Diagenesis may create secondary porosity which can be filled and preserved by later formed hydrocarbons. It may also be possible for secondary porosity to form during the genesis of liquid and gaseous hydrocarbons. This may arise through the release of carbon dioxide during maturation of the organic source material. This carbon dioxide can combine with water to produce carbonic acid which can leach out some of the constituents of the reservoir rocks and thus create secondary porosity.

Given the right set of circumstances and the amount of sandstone available on the Peninsula, it is possible that significant reservoirs may exist.

HYDROCARBON INDICATORS AND GEOCHEMISTRY

Direct Hydrocarbon Indicators

Oil and gas seeps on the Alaska Peninsula have been known for many years. Martin (1904, 1905) reported on the oil and gas seeps located between Becharof Lake and Puale Bay (then known as Cold Bay). These seeps led to some of the earliest exploratory drilling, in 1903, for petroleum on the Peninsula. Martin (1905) reported one or more of these seeps as having a large, constant flow of petroleum. Numerous investigators have mentioned these seeps in varying degrees of detail over the years (Brooks, 1923; Knappen, 1929; Blasko, 1976; Magoon et al., 1979).

Other seeps on the Peninsula have been reported over the years. Brooks (1923) reported a seep at Douglas River, seeps between Douglas River and Puale Bay, a seep on the Aniakchak River, and a seep near Chignik. Kellum et al. (1945), mentioned the reported occurrence of two seeps on Wide Bay, but were unable to confirm their presence. They did, however, locate and describe a 10-foot interbedded unit of coaly shale and fine- to medium-grained, shaly-weathering sandstone with some conglomerate that was 75 percent oil saturated. Keller and Reiser (1959), quoting Smith (1925), report gas seepage at Gas Creek near the headwaters of the Kejulik River (just north of Becharof NWR). Blasko (1976) reported on the occurrence of seeps in the Demian Hills just west of the southern portion of Becharof Lake.

Shows of oil and gas in various wells drilled on the Alaska Peninsula provide other direct indicators of hydrocarbon. One of the wells drilled in 1903 reportedly penetrated strata filled with thick residual oil (Martin, 1905). Five of the nine wells drilled along the northern shore of the Peninsula between 1957 and 1979 reportedly had oil and gas shows. The best shows of oil and gas occurred in the Gulf Sandy River No. 1 well, the Pan American Hoodoo Lake No. 2, and the Pan American David River 1-A (Marlow et al., 1979). Hanson et al. (1981), described the shows in the Pan American David River 1-A as weak gas flows in three intervals, and a trace of oil between 9,965 and 10,020 feet (3,270 to 3,287 m). Pan American Hoodoo Lake No. 2 had very weak gas shows and minor oil near 7,550 feet (2,477 m). The Gulf Oil Sandy River No. 1 encountered oil and gas shows below 10,000 feet (3,281 m).

Geochemistry

Knappen (1929) reported considerable organic material in the dark shales of the Naknek Formation in the Aniakchak area. Some of the rocks have a distinct petroliferous odor on a freshly broken surface; this is especially notable on the northwest side of Chignik Bay in Chignik Sandstone along the shore of Chignik Lagoon.

McLean (1977) reported on the geochemistry of samples from eight of the nine wells drilled on the Alaska Peninsula since 1957. He reported that the Lower Tertiary rocks are richer in organic carbon than are the Upper Tertiary rocks and that both are thermally immature. Woody kerogen predominates in these strata with a minor amount of amorphous-sapropel kerogen. Upon thermal maturity, woody kerogen tends to produce dry gas and amorphous-sapropel tends to produce liquid hydrocarbons.

McLean (1977) reported that various formations have a variable organic count (average 4 percent), have low values of extractable bitumen (average 41 ppm), have low hydrocarbon fraction (average 16 ppm), and have predominantly woody kerogen with minor amounts of amorphous-sapropel. The organic matter is mature with an average vitrinite reflectance of 1.76 percent, an absence of odd carbon preference, and C15-C22 hydrocarbons more common.

Lyle et al. (1979), reported that, based on outcrop samples, the Tertiary rocks are moderately mature and the Cretaceous rocks are moderately mature to very mature. They reported that herbaceous-spore/cuticle kerogen predominates with secondary amorphous, woody or coaly grain. This mix of kerogen types is, also, most likely to generate dry gas with minor amounts of liquid hydrocarbons.

HYDROCARBON POTENTIAL

We have classified (see Appendix A) the area around Frosty Peak, an active volcano, as having NO potential for hydrocarbon accumulation (plate 1). Most of the area of the Izembek NWR we have classified as having LOW potential for hydrocarbon accumulation. This area rates a LOW potential classification because of its nearness to Frosty Peak and because of the nature of the rocks in the Belkofski Formation. We have classified a small area of the refuge, to the northeast of Izembek Lagoon, as having a HIGH potential for the accumulation of hydrocarbons. This area rates HIGH potential classification because we project the formations in the Amoco Cathedral River Unit No. 1 well to extend into this area. We, however, have no subsurface data to confirm this.

PRODUCTION SCENARIO

An oilfield infrastructure does not exist near the Izembek NWR. Therefore, all infrastructure needed to produce and transport production to market would have to be built.

Should an economic field be discovered in Izembek NWR, development and production activities would begin on a year-round basis. Proposed plans for the production and transportation facilities are developed during the economic study of the discovery and submitted to local, state, and federal agencies for approval. After completing the required review process, the plans are either approved or denied pending further information, studies, and/or modifications. Once approved, construction of permanent drilling/production pads, air support facilities, roads, pipelines, and port facilities could begin. The first activity is to establish a temporary camp to support the construction workers who would begin constructing the permanent pads, connecting roads, airport, port, and a main road between the port facilities and the field. Selection of the port site is dependent upon the location of the field, economic, environmental, and water depth factors. Once the main road and port facilities are completed, the permanent camp and production facilities would be transported to the field and assembled onsite. These buildings would be designed to last the life of the field; depending upon the size of the field and the reservoir characteristics, one would expect the field to produce for 15 to 30 years.

Although a small portion of the Izembek NWR has been classified as high potential, there is insignificant data in this area to determine any possible hydrocarbon reservoir characteristics; i.e., depth and size of hydrocarbon accumulation. Therefore, an illustrative figure showing the location of the facilities needed to produce a prospect and subsequent disturbed acre and gravel requirement tables is not shown. If one desires an estimate of these factors, the figure and tables presented in the Alaska Peninsula and Becharof

Wildlife Refuge Assessment production scenario are applicable. All wells would be plugged and abandoned, facilities would be removed, and the disturbed surface would be reclaimed per federal regulations following the depletion of hydrocarbons from any prospect.

Production Facilities

Facilities needed for the production of oil and gas are the central production facilities, drilling/production pads, airstrip, pipelines, port facilities, and roads.

Central Production Facility (CPF)

The CPF is the headquarters and primary operations center for the production activities of a field. Only one CPF is anticipated, but surface and subsurface conditions may require more than one CPF to adequately produce a field. Pads needed to support housing and production modules would be approximately two feet thick.

Gravel, needed for the construction of the production facilities, will probably be mined near the field. To minimize environmental impacts, two or three small deposits may be excavated rather than removing the gravel needed from one source.

Housing modules would include sleeping and eating quarters, food storage area, and recreational and sanitation facilities. The modules would be designed to accommodate 150-300 workers. Adjoining offices would house administration, engineering, communications, and other support services.

Production facilities would include the equipment necessary to process the crude oil into salable oil and useable gas. This process begins by separating the production fluid into oil, gas, and water. Oil would be dehydrated and piped to the port facility. Produced gas could be dehydrated and compressed for facility use, reinjected into the subsurface structure, or piped to a NGL plant located at the port. Produced water would be pumped to injection wells for disposal.

Water for domestic use could be obtained from local lakes or water-filled pits (abandoned gravel source areas). Insulated tanks would store a sufficient amount of potable water for human consumption. Sewage treatment facilities and the incinerator would eliminate human waste and trash. Items which could not be burned would be transported to an approved disposal site.

Drilling/Production Pads

Drilling rigs and support modules would be the initial equipment located on the drilling/production pads. As wells are completed, wellheads, pipelines, and the gathering facility would be put in place. The size of these pads are dependent upon the number of wells drilled and the distance between wellheads. These pads would also be two feet thick.

Depending upon the proposed depth and subsurface conditions, production wells would take 10-60 days to drill and complete. Production from each well is piped to the gathering facility where it is metered and piped to the CPF.

Most production wells are directionally drilled from the pads to various bottom hole locations within the hydrocarbon reservoir. This procedure allows maximum depletion of the reservoir and minimizes the surface acreage disturbed. Unusable drilling mud and cuttings are temporarily stored in reserve pits located on the pad. As wells are completed, this material may be buried, when the reserve pit is filled in, or transported to a disposal site.

Airstrip, Pipelines, Roads, and Port Facilities

The airstrip would be permanent and maintained year-round for the lifetime of the project. Minimum length of the airstrip would be 6,000 feet and minimum width would be 150 feet.

Roads would connect all of the above facilities. They would be built with a crown width of 35 feet and would be two feet thick. Total road mileage varies between projects, depending on the size and surface features of each prospect.

Gathering lines would run from each production pad to the CPF. One line would transport the crude oil to the CPF and a parallel set of lines would transport the gas and water from the CPF to the production pads for fuel, injection, or disposal. Diameter of the pipe would range from three to twelve inches, and the pipelines would probably be buried parallel to the roads.

The main production pipeline leaving the field would probably be 8 to 16 inches in diameter for oil production and 3 to 8 inches in diameter for gas production (if an NGL plant is built). These lines would most likely be buried parallel to the main road.

Port facilities would include, as a minimum, oil storage, barge loading equipment, oil spill treatment center, ballast water treatment equipment, and, if enough gas is produced, a NGL plant. Also, a seawater treatment plant may be built if it is economically feasable to initiate a waterflood program.

When developing a secnario for the Izembek NWR, consideration must be given to the possibility of activity in the Bristol Bay area. Should a major discovery be made there, combined use of production and transportation facilities could be feasible. This would benefit both areas in the development of their "prospective" hydrocarbon resources.

ECONOMICS

There is a paucity in the availability of geologic knowledge for the Izembek NWR. This lack of information, coupled with a historic lack of industry interest in the area, is reflected in part in the subjective determination that the whole of this refuge either has a low economic development potential or none at all. As pointed out in the geologic portion of this report, there is little surface geologic data available for the refuge per-se, and since no wells have been drilled or seismic work conducted, we have no subsurface geologic data to aid in the evaluation process.

The geologic and geochemical data referred to in the body of this report pertains to the adjacent Alaska Peninsula NWR and other areas further up the peninsula and not directly to the Izembek NWR.

We classified one area in the refuge, the northeast corner (plate 1), as having a high geologic hydrocarbon potential. In contrast, we classify it as having a low economic development potential (plate 2). (In our report on the Alaska Peninsula and Becharof refuges, we classified this area as having a moderate economic potential when considered in the broader context of the northwestern portion of the Alaska Peninsula. Here, we consider it in the narrower context of the Izembek refuge and the geologic extrapolation which we made for this small area.) As pointed out in the geologic report, the main basis for the high geologic rating was due to the formations in the Amoco Cathedral River Unit No. 1 well being projected to extend into this area of the subject refuge. The Amoco well, drilled about 19 miles from the refuge boundary, was completed to a depth in excess of 14,000 feet in 1974. This well was subsequently declared a dry hole and was plugged and abandoned although some hydrocarbon shows were encountered.

The area that has been determined to have no geologic or development potential is the area around Frosty Peak, an active volcano (plate 2).

There is the possibility that significant reservoirs may exist beneath the surface of the Izembek NWR, but, based on the known subsurface geology from nearby areas and the risks involved, it is extremely doubtful that industry would be willing to expend exploration dollars in this area in the near future.

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APPENDIX A

3031 - Energy and Mineral Resource Assessment

Mineral Potential Classification System*

I. Level of Potential

O. The geologic environment, the inferred geologic processes, and the lack of mineral occurrences do not indicate potential for accumulation of mineral resources.

L. The geologic environment and the inferred geologic processes indicate low potential for accumulation of mineral resources.

M. The geologic environment, the inferred geologic processes, and the reported mineral occurrences and/or valid geochemical/geophysical anomaly indicate moderate potential for accumulation of mineral resources.

H. The geologic environment, the inferred geologic processes, the reported mineral occurrences and/or valid geochemical/geophysical anomaly, and the known mines or deposits indicate high potential for accumulation of mineral resources. The "known mines and deposits" do not have to be within the area that is being classified, but have to be within the same type of geologic environment.

ND. Mineral(s) potential not determined due to lack of useful data. This notation does not require a level-of-certainty qualifier.

II. Level of Certainty

A. The available data are insufficient and/or cannot be considered as direct or indirect evidence to support or refute the possible existence of mineral resources within the respective area.

B. The available data provide indirect evidence to support or refute the possible existence of mineral resources.

C. The available data provide direct evidence but are quantitatively minimal to support or refute the possible existence of mineral resources.

D. The available data provide abundant direct and indirect evidence to support or refute the possible existence of mineral resources.

For the determination of No Potential, use O/D. This class shall be seldom used, and when used, it should be for a specific commodity only. For example, if the available data show that the surface and subsurface types of rock in the respective area is batholothic (igneous intrusive), one can conclude, with reasonable certainty, that the area <u>does not</u> have potential for coal.

* As used in this classification, potential refers to potential for the presence (occurrence) of a concentration of one or more energy and/or mineral resources. It does not refer to or imply potential for development and/or extraction of the mineral resource(s). It does not imply that the potential concentration is or may be economic, that is, could be extracted profitably.

<u>Consideration of the Potential for Development and the Economic Potential</u>

Whenever <u>known</u>, the quality, quantity, current, and projected development potential or economic potential should be part of the mineral resource assessment. Although this is not necessary or required for most BLM actions, it is often useful to the decision maker. Assessments of economic potential should not be attempted for actions requiring low levels of detail, or when data are scant.

Development potential means whether or not an occurrence or potential occurrence is likely to be explored or developed within a specified timespan under specified geologic and nongeologic assumptions and conditions. Economic potential means whether or not an occurrence or a potential occurrence is exploitable under current or foreseeable economic conditions. The time period applicable to the economic or development potential assessment should be specified in the assessment report (e.g., the occurrence is likely to be exploited within the next 25 years). Conditions that could change the economic potential, such as access, world energy prices, or changing technology, shall be an important part of every economic potential assessment. Determining the economic or development potential of either an actual or an undiscovered mineral occurrence is a matter of professional judgment based on an analysis of geologic and nongeologic factors. The rationale for that judgment shall be part of the Mineral Assessment Report, when the economic potential is assessed. The rationale may include data on the current marketing conditions for the mineral commodity, technological factors affecting exploitability, distance from roads, anticipated capital costs, etc. In other words, if the economic or development potential is assessed, the rational for the conclusions regarding that potential must be thoroughly documented.

<u>Calculating</u> the quality of an occurrence, where the quality and quantity are not known from existing data, is only done for actions requiring a high level of detail. These calculations involve methods appropriate to the type of action and are described in the pertinent Bureau Manual (e.g., appraisal, validity, etc.).